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The dynamic equation of motion of driving mechanism of a freight elevator

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Abstract

Goal of the analysis of dynamics of a freight elevator is to find out, what acceleration will the lift be moving with. Value of the acceleration was found out with using system reduction method. Movement of the system was reduced to movement of elevator's cabin. The elevator's mechanism can be considered as planar mechanism with one degree of freedom in vertical direction. The third part of the document deals with applying the reduction method on a specific mechanism of freight elevator. Conclusion of the document contains analysis of the results, how do singular parameters affect the result and suggests ways, which the results could be verified in, or how to reach requested value and characteristics of the acceleration.

Keywords: freight elevator; Dynamics; acceleration; reduction method;

Nomenclature

v	velocity in the direction of (m/s)
r	radius of (m)
E_k	kinetic energy of system (J)
I_{red}	reduced moment of inertia of system (kg m^2)
P	system power (W)
α_M	angular acceleration (rad s^{-2})
ω_M	angular velocity (rad s^{-1})

1. Introduction

With buildings with more than one floor there came a problem with transport of men and material in a vertical direction. Except for other kinds of transport, we use elevators nowadays. Personal and freight elevators.

Freight elevators used in present are built in many different sizes, conceptions of driving mechanism setup and load capacity – from capacity of tens of kilograms to several tons. There are even bigger differences among nominal speed of

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every single elevator. It is connected with the dynamics of movement, especially acceleration and stopping of the elevator, which demands proper construction of the elevator.

This report deals with setting a dynamic equation of movement of mechanical system of a freight elevator‘s driving mechanism, especially with the dynamic conditions while the fully loaded elevator of 1 400 kilograms of load capacity is accelerating to its nominal speed.

The dynamic equation of motion of the mechanical system is set with using method of reduction of mass and force .

2. The dynamic equation of movement of the elevator’s driving mechanism.

2.1. Setting of the driving mechanism.

The alignment of mechanical system of the elevator with 5.5 kW electromotor installed and nominal speed of 0.2 ms^{-1} is shown in the Figure 1.

Fig. 1. Elevator’s driving machine

The elevator’s driving mechanism consists of a three-phase asynchronous motor, electro-mechanical brake, worm gear and traction sheave.

2.2. Kinematic scheme of the driving machine

The kinematic scheme of the elevator’s driving machine is shown in Figure 2. Mechanical system with a single degree of freedom and constant ratio consists of 11 elements. Their names and numbers are listed in Table 1.

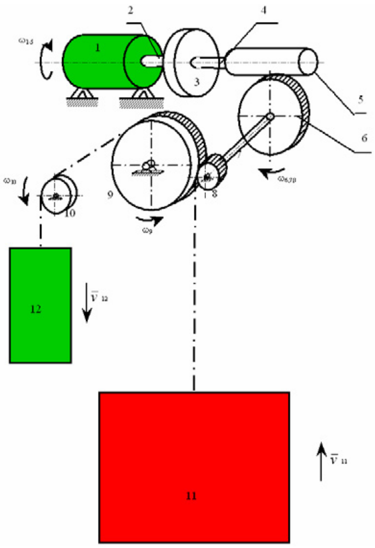

Fig. 2. Kinematic scheme of elevator’s driving machine

2.3. Mass and moments of inertia of the system's links

Program Autodesk® Inventor® was used to find values of mass and the moments of inertia of every single link of the mechanical system. There is a chosen CAD model of an element with the values highlighted in Figure 3.

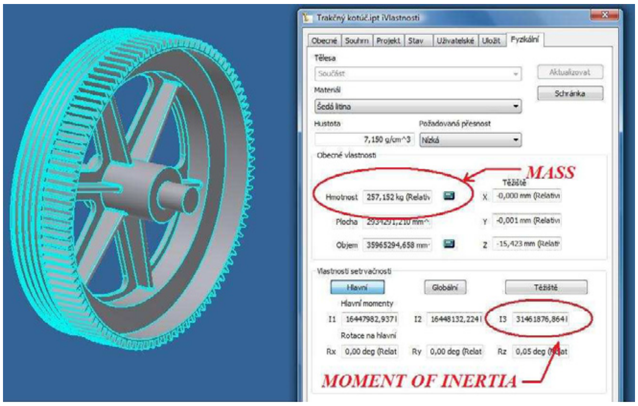

Fig.3. Value of mass and moment of inertia generated by the Autodesk® software.

Table 1. Values of mass and moment of inertia of the system's links

Link number	Link name	Mass [kg]	Moment of inertia [kg.m2]	Angular velocity [rad.s-1]	Kinetic energy [J2]
1	Rotor	----	0.052	98.96	254.62
2	Shaft 1	0.592	0.0001184	98.96	0.58
3	Brake	24.661	0.192668	98.96	943.41
4	Shaft 2	3.946	0.0007892	98.96	3.86
5	Worm	2.37	0.0007576	98.96	3.71
6	Worm wheel	14.8	0.295938	2.2	0.7156
7	Shaft 3	37.5	0.0299884	2.2	0.0725
8	Gear wheel	15.45	0.0689	2.2	0.1667
9	Traction sheave	187.3	31.462	0.43	2.91
10	Roller	47.6	2.56463132	1.25	1.992
------	------	----	----	Velocity	-----
11	Cage (cabin)	1580	----	0.2	31.6
12	Ballast	880	----	0.2	17.6
13	Cable 1	36.8	----	0.2	0.736
14	Cable 2	17.72	----	0.2	0.2944

2.4. The method of reduction

The force and mass reduction method was used to set the equation of movement. It is determined [1] :

$$E_{k\,red} = E_k, \qquad A_{red} = A, \qquad P_{red} = P, \tag{1}$$

where: $E_{k\,red}$ – kinetic energy of the reduced system,
A_{red} – work of the reduced system,
P_{red} – performance of the reduced system,
E_k, A, P – kinematic energy, work and performance of the original system.

The mechanism's movement is reduced to the elevator's cage's movement in a straight line with constant acceleration, which means that the equation of motion of the system will be:

$$m_{red} \cdot a_{11} = F_{red} \cdot \tag{2}$$

The values of the reduced mass of the system and the reduced force are determined from conditions (1). Then:

$$\begin{aligned} m_{red} &= \left(I_1 + I_2 + I_3 + I_4 + I_5\right) \cdot \left(\frac{r_{9\,g.wh.}}{r_9 \cdot r_8} \cdot z\right)^2 + \left(I_6 + I_7 + I_8\right) \cdot \left(\frac{r_{9\,g.wh.}}{r_9 \cdot r_8}\right)^2 + \\ &+ I_9 \cdot \frac{1}{r_9^{\,2}} + I_{10} \cdot \frac{1}{r_{10}^{\,2}} + m_{11} + m_{12} + m_{cable} \end{aligned} \tag{3}$$

$$F_{red} = \frac{P_1}{v_{11}} + \left(G_{12} - G_{11} - G_{cable}\right) - \frac{P_{pas.res.}}{v_{11}} \tag{4}$$

Necessary values of the kinetic energy of all links of the system and performance of the forces applied to the system were calculated in function of kinematic values of link 11 (elevator's cage) – velocity v_{11} and shift s_{11}.

After assignment into equation (2) and after calculation, the dynamic equation of movement will be:

$$65681\,kg \cdot a_{11} = 9\,416.4\ N$$

$$a_{11} = 0.1433\ m \cdot s^{-2} \tag{5}$$

Supposing constant acceleration of the elevator's cage, the cage will reach its nominal speed in approximately 1.4 s.

3. Conclusion

It is obvious from the results, that the value of the cage's acceleration is relatively small, but it is fully sufficient for the freight elevators and values of their nominal speed.

The performance of installed electromotor is high enough to run up fully loaded elevator.

In order to reach higher values of the acceleration it is necessary to reduce the reduced mass value as much as possible. The biggest influence on the reduced mass value have masses and kinematic ratios of the electro motor's rotor and brake.

It is necessary to try to reach as low values of passive resistance in the system as possible, because, for example, with neglected maintenance and insufficient lubrication we lose almost half of installed performance, needed to overcome passive resistances.

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